Description

COMPENSATION APPARATUS FOR PREVENTION OF DAMAGING BEARING CURRENTS IN AN ELECTRICAL MACHINE, AND A CORRESPONDING COMPENSATION METHOD

[0001]   The present invention relates to a compensation apparatus in order to compensate for bearing currents in an electrical machine, and to an electrical machine which is equipped with a compensation apparatus such as this. The present invention furthermore relates to a corresponding method for compensation for bearing currents.

[0002]   Nowadays, variable-speed motors are generally fed by voltage intermediate-circuit converters. These voltage-intermediate-circuit converters for feed purposes lead to bearing currents in the bearings of the motor. These bearing currents can lead to premature failure of the bearings, depending on the design of the motor. Failure is due to groove formation on the running suhigh-frequencyaces of the bearing (vibration, noise) and/or to decomposition of the bearing grease.

[0003]   Current-isolated bearings, for example bearings with ceramic insulation on the outer ring, are thus widely used in order to suppress bearing currents. Alternatively, hybrid bearings have been used, with steel rings and ceramic roller bodies in order to avoid bearing currents. However, these bearings are very expensive and are thus avoided, as far as possible. Furthermore, solutions in which the rotor is grounded by means of grounding brushes are known in order to prevent bearing currents. However, the grounding brushes are subject to wear and the contact reliability is not ensured, particularly in rugged environmental conditions. Furthermore, the Rockwell company have proposed in an "Industry White Paper" entitled "Inverter-Driven Induction Motors Shaft and Bearing Current Solutions" for a specific shield to be provided between the rotor

and the stator. Furthermore, in this context, converters are also known which use specific pulse patterns to reduce the bearing currents. All of these solutions have the common feature that they are relatively expensive and complex.

[0004]   The object of the present invention is thus to propose an electrical machine in which the problems relating to bearing currents are solved in a simple manner. A further aim is to specify a corresponding method.

[0005]   According to the invention, this object is achieved by a compensation apparatus for compensation for bearing currents in an electrical machine having a connection device for connection to at least one winding, to the housing and to the rotor of the electrical machine, and a voltage production device for production of a compensation voltage for the rotor of the electrical machine as a function of the operating voltage which is applied to the at least one winding, of the electrical machine.

[0006]   Furthermore a method is provided according to the present invention for compensation for bearing currents in an electrical machine by production of a compensation voltage for the rotor of the electrical machine as a function of an operating voltage of the electrical machine, and application of the compensation voltage to the rotor of the electrical machine.

[0007]   The compensation apparatus according to the invention, which is of simple design, applies an appropriate opposing voltage to the bearing, so that the electrical voltage which is caused on the bearings by the normal operating voltage on the electrical machine is compensated for. Currents therefore no longer flow via the bearing, and the life of the electrical machine can be correspondingly increased.

[0008]   The voltage production device of the compensation apparatus

according to the invention preferably has a transformer whose primary winding is connected between the at least one winding and the housing of the electrical machine, and whose secondary winding is connected between the rotor and the housing of the electrical machine. The transformer represents a cost-effective passive element for provision of the compensation.

[0009]   The transformer can be connected to networks, for example RC combinations, varistors, in order to adjust the compensation voltage individually for the machine.

[0010]   As an alternative to the transformer, the voltage production device may have an active circuit, by means of which the compensation voltage can be produced from the operating voltage which is applied to the electrical machine. An active circuit such as this makes it possible to carry out even more exact compensation.

[0011]   The operating voltage of the electrical machine frequently includes a common-mode voltage, which is a significant cause of bearing currents. It is thus advantageous to use the common-mode voltage as an input variable for the voltage production device. The bearing voltages are generally dependent on the common-mode voltage only via a motor-specific transformation disk.

[0012]   In one particular embodiment, the compensation apparatus according to the invention has a star circuit by means of which the phases of the electrical machine are connected at a star point, and in which the voltage at the star point is used as an input voltage for the voltage production device. This synthetically created star point means that there is no need to connect the windings of the machine at a star point, or for the star point to be accessible in the machine.

[0013]   A three-phase electrical machine is preferably equipped with the compensation apparatus. In this case, as already mentioned, it is particularly advantageous for a star point to be provided in the machine and for it to be possible to tap off the voltage at the star point as an input voltage for the voltage production device. This means that there is no need for a synthetic star point for production of the compensation voltage.

[0014]   The object mentioned above is also achieved by a compensation apparatus for prevention of damaging bearing currents having a first connection for connection to the rotor of an electrical machine, a second connection for connection to the housing or a potential of a voltage intermediate-circuit converter of the electrical machine, and an impedance with a low high-frequency reactance, which impedance is connected between the first and the second connection. An electrical machine according to the invention can be equipped with a compensation apparatus such as this. In this case, the idea is to ground the rotor via the compensation apparatus by only high frequencies. This makes it possible to avoid EDM bearing currents, that is to say the supply voltage for the motor is not used in this case.

[0015]   The present invention will now be explained in more detail with reference to the attached drawings, in which:

[0016]   FIG. 1   shows a circuit diagram of a motor which is supplied with a voltage intermediate-circuit converter in a two-point circuit;

[0017]   FIG. 2   shows a section drawing through a motor;

[0018]   FIG. 3   shows a single-phase equivalent circuit of the motor shown in Figure 2;

[0019]   FIG. 4   shows an illustration of a circular flow and of a bearing current;

[0020]   FIG. 5   shows an electrical equivalent circuit in order to explain the bearing current caused by circular flow;

[0021]   FIG. 6   shows the motor from Figure 2 with electrical circuitry;

[0022]   FIG. 7   shows the equivalent circuit, corresponding to the circuitry in Figure 6, with bearing current signal forms;

[0023]   FIG. 8   shows the circuitry according to the invention of a motor with a compensation apparatus which is connected to the star point of the motor winding;

[0024]   FIG. 9   shows the circuitry of a motor with a compensation apparatus, in which the star point of the motor is not accessible;

[0025]   FIG. 10   shows a circuit diagram of a compensation apparatus with active components; and

[0026]   FIG. 11   shows one example of a coupling device for coupling the compensation voltage to the rotor.

[0027]   The exemplary embodiments which are described in more detail in the following text represent preferred embodiments of the present invention.

[0028]   The reason for the converter-dependent bearing currents is the so-called "common-mode voltage" in the pulse pattern of the voltage intermediate-circuit converter UR, which is illustrated in Figure 1. The common-mode voltage U_o

which is applied to the motor DM can be measured directly, for example, between the star point and the motor housing if the motor windings are connected in star. The electronic switching element SE in the voltage intermediate-circuit converter UR switch the voltage U_d of the intermediate circuit ZK to the motor windings MW using a control method. A distinction is drawn between so-called on-line and off-line control methods. Irrespective of the control method that is used, the basic voltage waveform U_o at the star point SP is as shown in Figure 1. This voltage waveform results from the voltages U_{LL}, which are likewise shown in Figure 1, between the phases.

[0029]   Switching the electronic switching elements SE on and off leads to a change in the voltage across the parasitic capacitances in the motor, and thus to a current flow. Figure 2 shows these parasitic capacitances in a three-phase motor DM which has a stator ST and a rotor RO. The shaft WE of the rotor RO is borne on the stator ST via, for example, roller bearings WL. The voltage U is applied to the windings WI of the stator ST.

[0030]   This motor design (see also Figure 3) leads to a capacitance C_{wh} between the motor winding and the motor housing, a capacitance C_{wr} between the motor winding and rotor, a capacitance C_{rh} between the rotor and the motor housing, an effective capacitance C_b between the roller bodies and the bearing rings, a non-linear impedance Z_n of the lubricating film and an effective resistance R_b of the bearing comprising bearing rings and roller bodies.

[0031]   These electrical variables result in the single-phase equivalent circuit of a three-phase motor, as shown in Figure 3, including the electrical equivalent circuit for the impedance Z_b of the roller bearing WL. On this basis, the capacitance C_{wb} is connected between the phase U and ground PE. A series circuit formed by the capacitances C_{wr} and C_{rh} is arranged in parallel with this capacitance C_{wh}. The bearing impedance Z_b is once again connected in parallel

with the capacitance C_{rh}. This bearing impedance Z_b comprises a parallel circuit formed by the capacitance C_b and the lubricating film impedance Z_n, which is connected in series with the bearing resistance R_b.

[0032]   A change in the common-mode voltage U_o produces a current flow through the capacitance C_{wh}. This current results in a circular flow ZF in the motor windings MW which can lead to a damaging bearing current $I_{bearing}$, as is indicated in Figure 4. The bearing current $I_{bearing}$ passes through the laminated stator core of the stator ST, through the roller bearings WL through the rotor RO and, at the other end face of the three-phase motor DM, back through the roller bearing WL to the stator ST.

[0033]   The current I_e illustrated in Figure 5 through the capacitance C_{wh} is the source of the shaft voltage U_s. The shaft voltage U_s and the current I_e are transformer-linked by the design of the motor. The shaft voltage U_s is split between the two motor bearings. The equivalent circuits for the roller bearings at the drive end DE and at the non-drive end NDE of the motor are shown appropriately in Figure 5.

[0034]   The lubricating film in the roller bearing can provide isolation only for a specific voltage, and then breaks down. A damaging bearing current can now be formed. The breakdown voltage is dependent on the lubricating film thickness and thus on the rotation speed, the temperature and the load on the bearing. The breakdown voltage is in the range 0.3 ... 35 V. Bearing currents such as these have been described in the article by S. Chen, T.A. Lipo, D. Fitzgerald, "Modelling of bearing currents in inverter drives", IEEE Transactions on Industry Applications, volume 32, pages 21-31, 1996.

[0035]   According to the invention, the voltage across the roller bearings can be kept to values below the breakdown voltage by means of a suitable opposing

voltage U_k. This prevents the described bearing current caused by the circular flow. A current caused by the circular flow now flows via the compensation apparatuses (Figure 5).

[0036]   Damaging bearing currents may also be caused by discharge effects. In this case (see Figure 6 and Figure 7), the capacitance of the roller bearing C_b is charged via the capacitive voltage divider comprising C_{wr}, C_{rh} and C_b for as long as the lubricating film can provide isolation for this voltage. On reaching the breakdown voltage, the capacitance C_b is short-circuited within the bearing, and the capacitance C_{rh} is discharged into this short-circuit. As long as the lubricating film provides isolation, the voltage across the bearing is an image of the common-mode voltage corresponding to the transformation disk BVR (bearing voltage disk), which is predetermined by the motor design.

[0037]   The transformation disk BVR is governed by the disk of the voltage U_{zb} across the bearing impedance Z_b and the voltage U_{Cwh} across the capacitance C_{wh}. This disk is typically between 0.02 and 0.2. Figure 7 shows the voltage waveform U_{zb} for a small value of BVR and for a large value of BVR. In this case, the circuit and the motor winding are supplied with half the intermediate-circuit voltage 0.5 U_d via an impedance Z, with this voltage having the same signal waveform as the voltage U_{zb}. In this case as well, charging of the bearing can be prevented by a suitable opposing voltage U_k.

[0038]   A circuit KS1 or KS2 (see Figure 8 or Figure 9 respectively) according to the invention is used to compensate for the bearing voltage U_{zb} produced by the common-mode voltage U_o. The common-mode voltage U_o connected to the motor terminals is either used directly (Figure 8) or is modeled (Figure 9) for this purpose. The compensation circuit KS1 or KS2 uses the common-mode voltage U_o to produce an opposing voltage in order to minimize the bearing currents. It may be designed using passive or active components. This is

injected at the drive end (DE) or at the non-drive end (NDE) depending on the design of the motor DM, in order to produce the desired compensation. The compensation voltage or opposing voltage can also be injected capacitively by means of a capacitor C_{KR} (Figure 9).

[0039]   The respective compensation device KS1 or KS2 is, in its simplest form, a pulse transformer or transformer T which applies the common-mode voltage U_o with an appropriate mathematical sign to the rotor RO as the opposing voltage, corresponding to the BVR of the motor. The common-mode voltage U_o reaches up to half the intermediate-circuit voltage U_d with conventional voltage intermediate-circuit converters. If, for example, the BVR is 5% and the common-mode voltage U_o is 300 V, the opposing voltage that must be produced is 15 V. The opposing voltage may be applied to the rotor RO via a sliding contact or via a capacitive coupling device.

[0040]   The pulse transformer T is provided with circuitry networks Z_{T1}, Z_{T2} in order to match the voltage form to the opposing voltage. This circuitry Z_{T1}, Z_{T2} may, for example, be an RC combination and/or a varistor.

[0041]   The pulse transformer T is fed via one or more coupling capacitors. If the common-mode voltage U_o is available at the star point SP (see Figure 8), only one coupling capacitor C_{KO} is required, and is connected to the star point SP of the motor winding MW. If this star point SP is not available (see Figure 9), for example in the case of a delta-connected winding, the coupling capacitors C_{K1}, C_{K2}, C_{K3} are connected to the motor terminals U, V, W. The three coupling capacitors C_{K1}, C_{K2}, C_{K3} form a star point SP', at which the common-mode voltage U_o is formed.

[0042]   As shown in Figure 10, the compensation apparatus KS3 can also be designed with active components, and if required digitally. The auxiliary energy Uh for supplying the active circuit AS can be obtained from the motor voltage, or

can be provided externally. The common-mode voltage U_o is either recorded directly or is obtained via a network NW or from the drive signals of the voltage intermediate-circuit converter UR. An opposing voltage is determined from the common-mode voltage U_o and from the motor data, and is passed to the rotor via an amplifier AMP and the coupling device C_{KR}.

[0043]   The active circuit (AS) can also be designed such that the compensation apparatus KS3 provides a high-frequency ground for the rotor, irrespective of the common-mode voltage U_o.

[0044]   A sliding contact is avoided, in order to connect the opposing voltage to the rotor reliably and without wear. Figure 11 shows one implementation option for the coupling device C_{KR}. In this case, a bush BU is plugged over the rotor shaft WE, and is centered with an isolating part IT. The bush BU together with the rotor shaft WE forms a cylindrical capacitor.

[0045]   The bush BU and the isolating part IT may also, for example, be in the form of one component, which is mounted in the same way as a bearing.

[0046]   No expensive current-isolating bearings or hybrid bearings for the prevention of damaging bearing currents are required when using the compensation apparatus KS1 to KS3 according to the invention. The life of the bearing is then advantageously increased, without the bearing currents, owing to the lack of groove formation or reduced grease aging.